**Chemical Equilibrium Exercise**

Objective: Students will be able to use the concept of chemical equilibrium to explain how increasing CO2 in atmosphere and increasing global temperatures can affect the acidity of the oceans.

These four Causal Principles will be used in this exercise:

2. At equilibrium, energy is balanced and no net change occurs.

3. At equilibrium, there is a fixed concentration of atoms and molecules in different phases or materials.

*3a. In this exercise we will elaborate the concept of chemical equilibrium using the concepts of saturation and material balance.*

6. Change in temperature causes molecules to move faster or slower.

8. When molecules move faster, it is easier to break bonds.

**Chemical Equilibrium and the Concept of Saturation**

**Part 1 Sponge and water vapor**

When a solution such as seawater or magma is at *equilibrium*, it is said to be *saturated*. Saturation is easy to understand because it works just like a sponge in a pool of water (figure 4). There are three degrees of saturation; 1) undersaturated, saturated and supersaturated.

1) The sponge is *saturated* (at equilibrium)- At saturation the sponge is filled with water. If the sponge is in a pool of water, it will not absorb any more water

2) The sponge is *undersaturated* (not at equilibrium)- At undersaturation the sponge may still hold more water. If the sponge is in a pool of water, it can absorb more water

3) The sponge is *supersaturated* (not at equilibrium)- At supersaturation the sponge has excess water that is leaking out of it. If the sponge is in a pool of water, some water will leak out of the sponge and enlarge the pool.

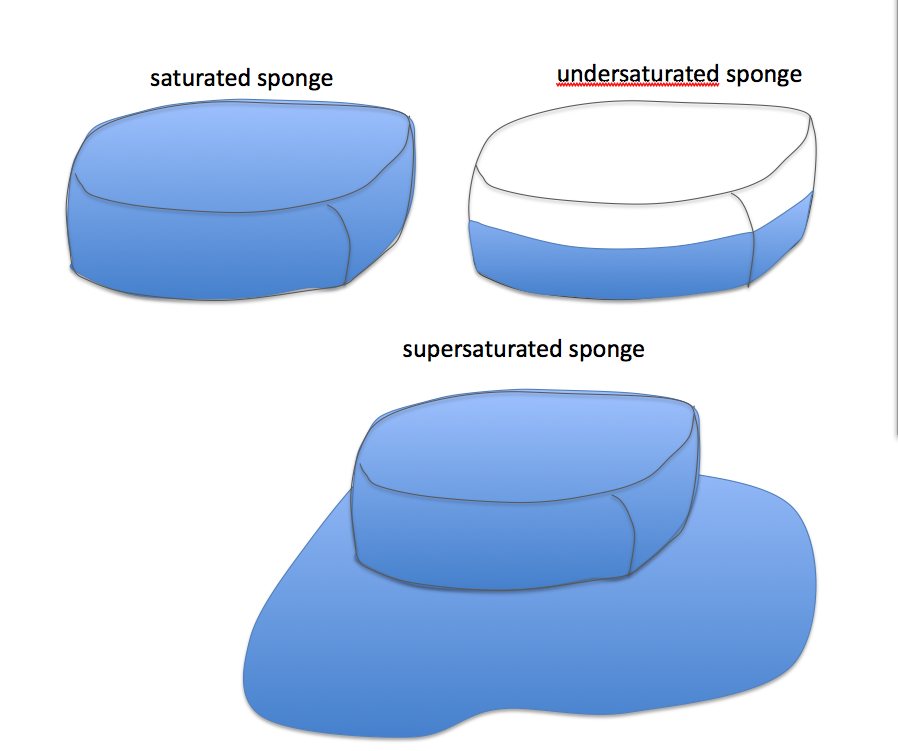


Figure 1. Three stages of saturation of water in a sponge; saturated, undersaturated and supersaturated.

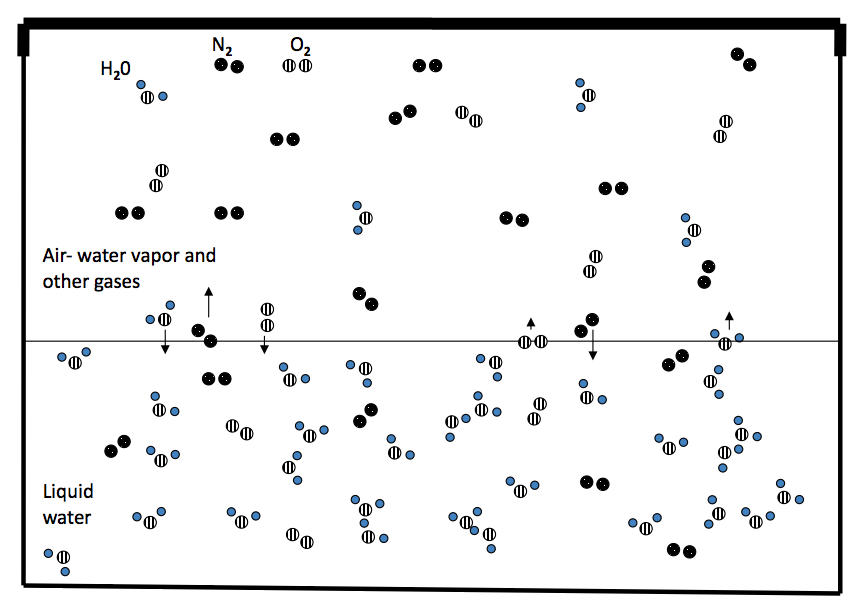
We can apply this idea of saturation and equilibrium to liquid water in equilibrium with water vapor in a sealed container (Figure 2). 

Figure 2. A molecular view of liquid water and water vapor in a sealed container.

If the liquid water is placed in a container with very dry air, at first there will be very little water vapor in the air. The air will be udersaturated with respect to water vapor. It will take a while for the air to become saturated with water vapor. Once it is saturated with water, the liquid and water vapor are at equilibrium. Once the air is saturated with water vapor it cannot hold any more water vapor. If water vapor is added to the saturated air, some of the vapor will condense until the liquid water and water in the air are once again at equilibrium.

**Similar Features**

Complete table 1 showing the similarities between liquid water in a sponge sitting in a pool of water and water vapor in a sealed container containing liquid water. The sponge will be like the air in the container and water vapor in the container will be like liquid water in the sponge.

|  |  |
| --- | --- |
| ***sponge in water*** | ***vapor in sealed container with liquid water*** |
| sponge | *air* |
| pool of water in which sponge sits | *liquid water* |
| liquid water in sponge | *water vapor* |

Table 1

**Similar Relationships**

The important relationships in the sponge and water in a sealed container are the degrees of saturation; undersaturated, saturated (= at equilibrium) and supersaturated. Complete table 2 by stating the characteristics of each of these relationships in the sponge and container.

|  |  |  |
| --- | --- | --- |
| **Relationship** | **Sponge in pool of water** | **Water vapor in sealed container** |
| **undersaturated** | *Pool of water is less than the amount of water the sponge can hold. The sponge soaks up all the water from the pool.* | *Water vapor in jar is less than the amount of vapor the air can hold* |
| ***saturated*** | *The pool of water is greater than the amount of water the sponge can hold. Sponge is filled with water.* | *Water vapor in air is at a maximum it can hold.* |
| ***supersaturated*** | *The sponge is overfilled with water. Water leaks out of the sponge into the pool.* | *Excess water vapor in the air* |

Table 2

One way to change the equilibrium of water vapor and liquid water in a sealed container is to change the temperature of the sealed container. What would happen if the temperature of the container were increased or decreased? We know from our experience that the amount of water vapor would be higher at higher temperatures and lower at lower temperatures. This makes sense to us when we remember that temperature is simply a measure of the average speed of molecules. When the temperature of water increases, then more molecules can escape from the liquid and enter the vapor phases.

We can also change the amount of water a sponge can hold by squeezing the sponge. Squeezing a sponge is similar \_\_\_\_\_\_\_\_\_\_\_\_\_ the temperature of a container of liquid water and water vapor.

Clearly, you expend some energy when you squeeze a sponge. Recall that energy is required to break bonds and energy is released when bonds form. At equilibrium, the amount of energy used to break bonds is equal to the amount of energy being returned through the formation of new bonds.

The idea of chemical equilibrium is often expresses by an equation (e.g. equation 1). Many people don’t like equations but I think you’ll see a simplicity and usefulness to them. We’ll begin with equilibrium between liquid water and water vapor. The chemical equation is simply:

H2O (liquid) H2O (vapor) equation 1

Notice the arrows going both ways. This means that, at equilibrium, the amount of water changing from liquid to vapor is equal to the amount of water changing from vapor to liquid.

**Part 2 Sponge and solid dissolved in water**

We can extend the idea of a sponge in a pool of water to chemical reactions that involve dissolution and precipitation of solids in water. A useful example of a solid reacting in water can be observed by pouring salt in a glass of water. When a little salt is pour in, it dissolves. Table salt is sodium chloride (NaCl) and it dissolves into sodium (Na1+) and chloride (Cl1-) ions. The formula for this chemical reaction:

NaCl Na1+ + Cl1- equation 2

If you continue to pour salt into the glass of water, eventually no more salt will dissolve. If you pour a little more salt into the glass, it will simply accumulate on the bottom of the glass. If the glass is left uncovered, water will evaporate but the sodium and chloride ions will remain with the remaining water. As the water evaporates sodium and chloride ions in the water will combine to form more solid salt on the bottom of the glass.

**Similar Features**

In table 3 list feature similarities between a sponge in a pool of water and salt that may dissolve in a beaker of water.

|  |  |
| --- | --- |
| **Sponge in water** | **Salt in water** |
| sponge | *Water in the beaker* |
| pool of water | *Solid in the water* |
| water in the sponge | *Dissolve solid in the water. In the case of a solid such as salt (NaCl) the dissolved solids would be Na and chloride ions (Na1+ and Cl1-)* |

Table 3

**Similar Relationships**

The important relationships in the sponge and salt in water are the degrees of saturation; undersaturated, saturated (= at equilibrium) and supersaturated. Complete table 4 by stating the characteristics of each of these relations in the sponge and container.

|  |  |  |
| --- | --- | --- |
| **Relationship** | **Sponge in water** | **Salt in water** |
| **undersaturated** | *Pool of water is less than the amount of water the sponge can hold. The sponge soaks up all the water from the pool. The sponge is not full of water.* | *The amount of solid is less than the amount of dissolved solid the water can hold* |
| ***saturated*** | *The pool of water is greater than the amount of water the sponge can hold. The sponge full of water.* | *The solid is greater than the amount of dissolved solid the solution can hold.* |
| ***supersaturated*** | *The sponge is overfilled with water. Water leaks out of the sponge into the pool.* | *The solution has an excess of ions. Ions leave the solution and are added to the solid.* |

Table 4.

**Part 3 Two sponges and gas dissolved in water**

*Not all types of chemical equilibrium can be described by the concept of saturation.* In some cases*,* equilibrium is due *to material balance.* This situation is similar to two sponges in contact with one another.

If two of the same kind of sponges are in contact with each other, the amount of water in each would be the same (Figure 2).

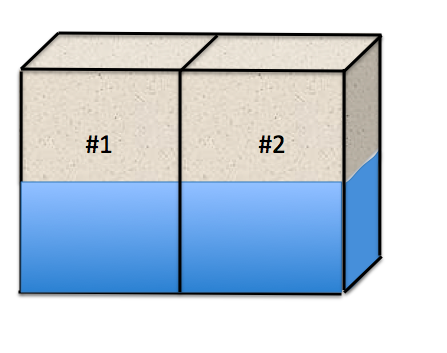


Figure 2. Two sponges in contact with each other equilibrate to have the same amount of water in each.

If one of the two sponges had more water than the other (Figure 3A) water would flow from the sponge with more water to the sponge with less water until a new equilibrium was established (Figure 3B)

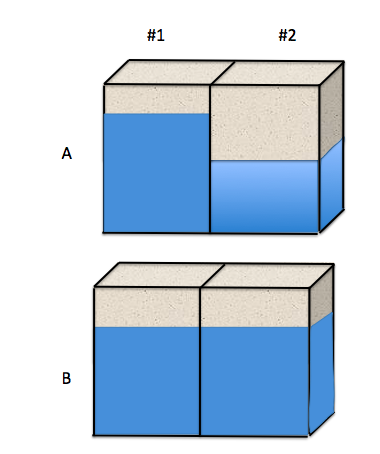


Figure 3. If one of two sponges in contact with each other has a different amount of water, water will flow form one sponge to another until the amount of water in each is the same.

Another possibility is that the two sponges are made of different materials so that one sponge can hold more water than the other (Figure 4). In this case, the two sponges could be at equilibrium but have different amounts of water. This situation of a balance of material in different kinds of sponges applies to most chemical reactions.

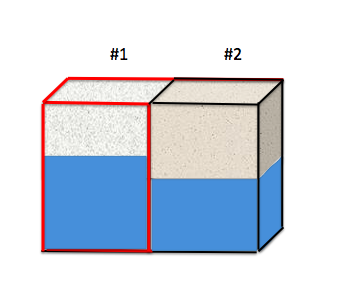


Figure 4. Two spnges in contact with each other can, at eqiulibrium, have different amounts of water if the sponges are made of different materials.

Now we will look at some chemical reactions that are similar to a balance of materials in connected but different kinds of sponges. The first reaction we will examine involves carbon dioxide gas in a sealed vessel containing liquid water and air. We can describe what is going on with the following equation.

CO2 (gas in water) CO2 (gas in air) equation 3

How would you have guessed to write such an equation? Perhaps you’ve opened a bottle of pop or sparkling water and noticed the bubbles rising. Those bubbles are carbon dioxide gas that was dissolved in the liquid. When you opened the bottle you released pressure. At lower pressure, some dissolved gas was released form the liquid.

At equilibrium some of the carbon dioxide gas will be in the gas above the liquid water and some will be dissolved in the water. So gas may be saturated, undersaturate or supersaturated in either the air or the water. Because the gas can be in either air or water, we can think of this as similar to two sponges in contact with one another.

**Similar features**

Describe the similarities between sponges #1and #2 in figure 4 and the chemical reaction described by equation 3 by completing table 5. The fact that sponge 1 is associated with CO2 gas in air and sponge 2 is associated with CO2 gas in water is because air can hold a greater amount of CO2 gas than water.

|  |  |  |  |
| --- | --- | --- | --- |
| **Sponge # 1** | **CO2 gas in air** | **Sponge #2** | **CO2 gas in water** |
| sponge | *air* | sponge | *water* |
| water in sponge #1 | *CO2 gas* | water in sponge #2 | *CO2 gas* |

Table 5

**Similar relationships**

Complete table 6 by listing the changes that would occur in the sponges and the analogous chemical reactions in respond to an increase or decrease in the amount of water in sponge #1.

|  |  |  |  |
| --- | --- | --- | --- |
| **Sponge # 1** | **CO2 gas in air** | **Sponge #2** | **CO2 gas in water** |
| increase water | *increase CO2 gas in air* | *increase water* | *increase CO2 gas in air* |
| decrease water | *decrease CO2 gas in air* | *decrease water* | *decrease CO2 gas in air* |

Table 6.

**Part 4 Two sponges and gas reacting with water.**

Our discussion began with simple molecules that enter or leave a solution. However, many chemical reactions involve changes in the composition of molecules within a solution. In fact, when carbon dioxide dissolves in water there is a very important change in the composition of some molecules as shown in equation 4.

H2O (liquid) + CO2 (gas in water) H++ HCO3- equation 4

H+is the hydrogen ion. HCO3 – is the bicarbonate ion. Both are ions in water.

This reaction is an example in which chemical changes are similar to two sponges in contact with each side of the equation being a different sponge (Figure 4). We can think of this as molecules moving back and forth between the two sponges.

**Similar features**

Complete table 7 by listing the features in the chemical equation 4 that correspond to the sponges and water in two connected sponges.

|  |  |  |  |
| --- | --- | --- | --- |
| **Sponge #1** | **CO2 gas + H2O** | **Sponge #2** | **H++ HCO3-** |
| sponge | *water* | *sponge* | *water* |
| water | *CO2 gas + H20* | *water* | *H++ HCO3-* |

**Table 7**

**Similar relationships**

Next consider what would happen to the two sponges if material were added to one sponge but not the other. This is depicted in figure 3. The water in sponge #1 (figure 3A) disturbs the equilibrium, which becomes re-established when some of the water in sponge #1 flows into sponge #2.

Complete table 8 by listing the changes that would occur in the sponges and the analogous chemical reactions in respond to an increase or decrease in the amount of water in sponge #1

|  |  |  |  |
| --- | --- | --- | --- |
| **Sponge #1** | **CO2 gas + H2O** | **Sponge #2** | **H++ HCO3-** |
| increase water | *increase CO2 gas + H20* | *increase water* | *increase H++ HCO3-* |
| decrease water | *decrease CO2 gas + H20* | *decrease water* | *decrease H++ HCO3-* |

Table 8

Equation 3 is an important reaction for the global environment because H+(hydrogen ions) determine the acidity of water. Waters with high amounts of hydrogen ions are more acid than water with low amounts of hydrogen ions and acid waters can threaten many kinds of plants and animals.

**Part 5 The role of temperature in chemical equilibrium**

Changing the temperature of a system is similar to squeezing or expanding a sponge. We’ll start thinking about the role of temperature in chemical reactions by recalling two of our basic principles.

Principle 6: Change in temperature causes molecules to move faster or slower

Principle 8: When molecules move faster, it is easier to break bonds.

These principles help us explain a few simple observations.

1) When liquid water is heated, more water vapor forms.

2) Cold water can dissolve more carbon dioxide than hot water.

3) Hot water can dissolve more table salt (NaCl) than cold water.

In table 9, the three relationships above are listed in columns 1& 2. Complete table 9 by listing which principle (6 or 8) are similar by filling in column with either principle 6 or principle 8 is the basis of the similarity.

|  |  |  |
| --- | --- | --- |
| Hot water dissolves more salt than cold water | Hot water creates more water vapor than cold water | *principle 8* |
| Hot water creates more water vapor than cold water | Hot water releases more dissolved CO2 than cold water | *principle 6* |
| If a hot solution in equilibrium with salt cools, more solid salt will form. | If hot water in equilibrium with water vapor is cooled, more liquid water will form | *principle 8* |

Table 9

Even with our general principles, it is not always possible to predict how things will change with temperature. Sometimes we need observations. For example, we can use the principles to predict that cold water can hold more carbon dioxide than warm water. But what about equaton 3 (H2O (liquid) + CO2 (gas in water) H++ HCO3-)? We have provided you with no information about how temperature affects H++ HCO3- ions. In fact, it does affect them but not nearly as much as it affects the ability of CO2 to dissolve in water.

**Evaluation Inference**

Fish use gills to extract dissolved oxygen from water. Based on the preceding answers the following true/false questions.

1. Warm water will have more dissolved oxygen than cold water. T/***F***

2. If the oxygen content of the atmosphere were to increase, the amount of dissolved oxygen in the oceans would also increase. ***T***/F

3. If organisms in the oceans were to increase the amount of oxygen they consume, more oxygen from the atmosphere would dissolve on the oceans. ***T***/F

**Assessment:**

Carbon dioxide emissions are presently making the oceans more acidic. The chemistry that shows this is simple and depicted in the equation below.

CO2 + H2O HCO3- + H+

HCO3- is an ion called bicarbonate. H+ is the hydrogen ion. The acidity of seawater is a measure of the amount of hydrogen ions in the water.

We do not have time in this course to describe the biological effects of ocean water acidity but if you who have ever had a fish tank may recall that you added chemicals to the tank to prevent it from becoming too acid. The reason that your tank needed this treatment is that organic matter (mostly fish feces) decay in the bottom of the tank producing CO2.

1) Using the concept of chemical equilibrium, explain why increasing carbon dioxide in the atmosphere may lead to increased acidity of water.

*If there is more CO2 added to the water then material balance requires that more HCO3- + H+ be created to re-establish equilibrium*

2) Using the concept of chemical equilibrium, explain why increasing global temperature may lead to decrease in acidity of seawater.

*If temperature increases, less CO2 can dissolve in water. If the amount of CO2 in water decreases, then the amounts of HCO3- + H+ will decrease making water less acid.*